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Water-Vapor-Barrier Coatings for Polyurethane Foams

June 1976

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U.S. Army Materiel Development
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| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The water-vapor transmission rates through a polyether type of polyurethane foam with and without vapor-barrier coatings were determined at 70°C and 91-percent relative humidity. The data indicate that polyurethane foam encapsulation cannot provide satisfactory protection from moisture penetration. The moisture transmission is more severe for low-density foam. Two low-molecular-weight, butyl-rubber coating materials and one epoxy | | | |

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compound were shown to form good coatings on the foam and resulted in 37- to 95-percent transmission-rate reductions when the coatings were nominally 0.020 in. thick.

CONTENTS

| | <u>Page</u> |
|---|-------------|
| 1. INTRODUCTION | 5 |
| 2. EXPERIMENTAL | 5 |
| 2.1 Materials | 5 |
| 2.2 Preparation of Foam Specimens | 6 |
| 2.3 Application of Water-Vapor-Barrier Coating | 6 |
| 2.4 Water-Vapor-Transmission-Rate Determination | 7 |
| 3. RESULTS AND DISCUSSION | 9 |
| 3.1 Coating Material and Application | 9 |
| 3.2 Water-Vapor Transmission | 10 |
| 4. CONCLUSIONS | 13 |
| ACKNOWLEDGEMENT | 13 |
| LITERATURE CITED | 13 |
| DISTRIBUTION | 15 |

FIGURES

| | | |
|---|--|---|
| 1 | Test Dish for Water-Vapor Transmission-Rate Determinations. | 7 |
| 2 | Specimen Assemblies Ready for Water-Vapor Transmission-Rate Determinations | 8 |

TABLES

| | | |
|-----|--|----|
| I | Materials Used in Polyurethane-Foam Study | 5 |
| II | Water-Vapor Transmission Rates of 24-lb/ft ³ Polyurethane Foam at 70°C and 91-Percent Relative Humidity | 11 |
| III | Water-Vapor Transmission Rates of 6-lb/ft ³ Polyurethane Foam at 70°C and 91-Percent Relative Humidity | 12 |

1. INTRODUCTION

Rigid polyurethane (PU) foam has been widely used in our laboratories for encapsulating electronic components because of its light weight and excellent insulation property. Quite often, the foam in use is not sealed in an enclosure, or there is a time interval before it is sealed. Since the foam does not usually have 100-percent closed-cell structure, there is always a risk of moisture penetration. Questions that arise are how fast the moisture penetration is and what vapor barrier can be applied to reduce the rate. This report presents our measurements of the water-vapor transmission rates (WVTR's) of the PU foams of various densities and the effectiveness of several vapor-barrier coatings.

2. EXPERIMENTAL

2.1 Materials

The materials used in this work are described in table I. The thermal properties of the butyl rubber were determined by differential scanning calorimetry (DSC).

TABLE I. MATERIALS USED IN POLYURETHANE-FOAM STUDY

| Name | Supplier | Composition |
|--|------------------------------------|--|
| Isofoam PE series | Isocyanate Products, Inc. | Polyether type polyurethane rigid foam: part A, prepolymer of TDI and ether glycol resin; part B, ether glycol resin with some diamine and water; closed-cell content, 95% min |
| Butyl-rubber coating compound PC8101/66, black | U.S. Polymeric | 8.17 lb/gal, 35% solids by volume in toluene, carbon filled: parts A/B containing different catalysts, used in wt ratio of 24.4:23.4 with 1 g of accelerator |
| Butyl rubber Foamseal 57-80 | Foster Div., Amchem Products, Inc. | Part A, 8.5 lb/gal, 41% solids by volume in xylene, aluminum filled; part B, activator; A/B wt ratio of 23.5:1 |
| Hysol PC-12-007 | Hysol Corp. | Bisphenol-A type epoxy cured with polyamide and others, 100% solids |
| Daran 220 latex | W. R. Grace & Co. | Polyvinylidene chloride coating latex, 60 to 62% solids |
| Saran resin F310 | Dow Chemical Co. | Vinylidene/acrylonitrile copolymer, white powder, heat seal range 250 to 350°F |

2.2 Preparation of Foam Specimens

Foam specimens used for the determination of WVTR's are discs of 5.25-in. diameter and approximately 0.81-in. thickness. The foam was prepared with a Martin Sweets Co. model 2-3L foam machine capable of delivering 10 g of mixed foam ingredients to an accuracy of 1 percent at preheat temperatures as prescribed by the PU foam material supplier. The machine was fitted with a Miniature model, 7/8-hp mixing head. A preset amount of the mixed ingredients of the PU foam material was delivered from the mixing head to a mold, which was precoated by spraying with a thin layer of mold release agent MS-122 (Miller-Stephenson Chemical Co., Inc.). The mold was an aluminum ring, 5.25 in. i.d. \times 6.27 in. o.d. \times 0.85 in. high, clamped on each side with an aluminum plate of 0.340-in. thickness. The total weight of the clamped mold was about 5.7 lb. For the preparation of 6-lb/ft³ foam, Isofoam PE-6 was used, and the mold was preheated to 70°C. For the 24-lb/ft³ foam, Isofoam PE-18 was used, and there was no preheating of the mold. As soon as the foam expanded to the filling hole of the mold, it was put in an oven at 70°C for a 4-hr cure (the filling hole was plugged for the 24-lb/ft³ foam).

After curing, the foam disc was removed from the mold, examined for defects, and machined to remove the sprue and to make the two sides skinless, smooth, and parallel. The foam density was checked and found usually to be within a ± 5 -percent limit.

2.3 Application of Water-Vapor-Barrier Coating

Different coating materials required some different coating techniques. Satisfactory coatings were obtained with butyl rubbers PC8101/66 and Foamseal 57-80 and epoxy Hysol PC-12-007. The coating method can be generally described as follows: The machined disc specimen was wiped clean and put back into the mold ring. Shim pieces were inserted under the foam to make the foam surface lower than the mold ring by the thickness of the coating to be applied. The components of the coating materials were blended according to the manufacturer's instructions, and the blend was deaired under vacuum. To make a coating 0.010 to 0.020 in. thick, two to three coats were applied, with each coat dried at room temperature overnight. The final coat was leveled with the rim of the mold ring by drawing a rod across the surface. After being dried or gelled, the coated specimen was removed from the mold ring and cured for 4 hr at 70°C in an oven. (The manufacturers recommend a cure cycle of 2 wk at 25°C for the butyl-rubber coating. The 70°C cure cycle is equivalent to the slow room-temperature cure.)

2.4 Water-Vapor Transmission-Rate Determination

The ASTM C355-64 desiccant method was followed, except for the design of the test dishes. For the convenience of mold making, disc specimens were prepared, and hence the test dishes used were similar to the dish prescribed in ASTM E96-66, which is a method for the WVTR determination of materials in sheet form. The test dish, as shown in figure 1, was cast with a glass-filled rigid epoxy, Epocast 220 of Furane Plastics. The template ring holder was made of Plexiglas. After 120 g of anhydrous calcium chloride (12 mesh available and used instead of the 8 mesh suggested) and 10 g of indicating Drierite were placed in the dish, the disc specimen was put in place and sealed with an O-ring on each side under the pressure of the template ring holder tightened with four Allen setscrews. The O-ring used was made of nitrile rubber (Shore A 70). The small gap between the tightened ring holder and the dish was sealed with an ample amount of Dow Corning 3145 RTV adhesive-sealant material.

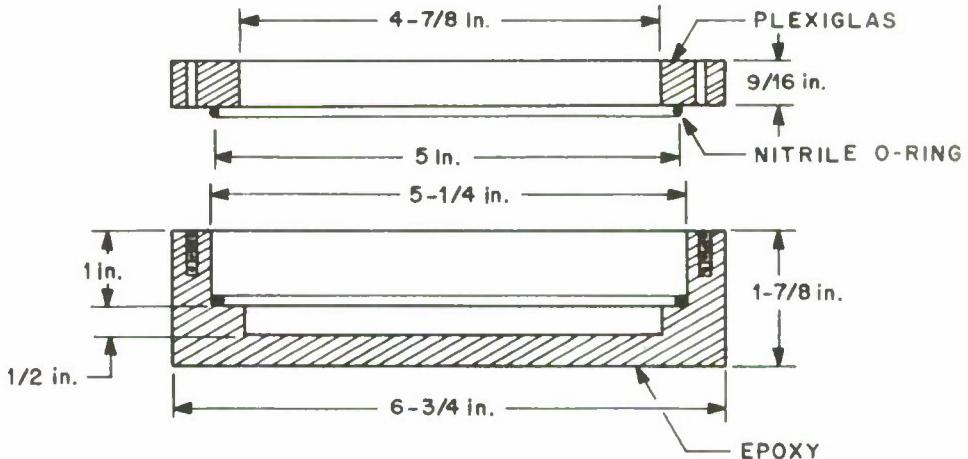


Figure 1. Test dish for water-vapor transmission-rate determinations.

The sealed specimen assembly (fig. 2) was weighed and placed in a temperature-humidity chamber, Hotpack model No. 47559. The chamber was maintained at $70 \pm 1^\circ\text{C}$ and 91-percent relative humidity (RH) and monitored by a recorder. The assembly was removed at the end of each week, weighed, and replaced immediately. The test was continued until a nominal steady state was shown by plotting the weight against elapsed time (usually 4 to 7 wk). At the end, the specimen was visually examined, and the desiccant was checked to see that no excessive amount of water was absorbed. Three specimens were normally tested for each foam sample.



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Figure 2. Specimen assemblies ready for water-vapor transmission-rate determinations.

The slope of the straight line was read from the plot of the weights against elapsed time. The WVTR was calculated according to the equations given in the ASTM method:

$$\text{WVTR} = G/tA, \quad (1)$$

where

G = weight change in grams,
 t = time elapsed in hours,
 A = test area = $\pi(5/2)^2 \text{ in.}^2 = 1.266 \times 10^{-2} \text{ m}^2$.

$$\text{Permeance} = \frac{\text{WVTR}}{S(R_1 - R_2)}, \quad (2)$$

where

S = saturation vapor pressure at test temperature, 233.7-mm Hg,
 R_1 = relative humidity at source = 91 percent,
 R_2 = relative humidity at sink = 0 percent.

3. RESULTS AND DISCUSSION

3.1 Coating Material and Application

The primary interest of this work is to select and test some polymeric materials that are commercially available and inexpensive, have low water-vapor permeability, and can be easily applied on PU foam to form a continuous film as a vapor-barrier coating. The vapor transmission through homogeneous films of polymeric materials is of the activated diffusion type--namely, a process in which vapor dissolves in the polymer and then diffuses through and evaporates from the other surface. Therefore, transmission depends on the solubility of vapor and on the diffusivity of the dissolved vapor in the polymer medium. Polymer properties that affect the transmission include density, molecular weight, chemical structure, crystallinity, orientation, crosslinking, and the presence of plasticizers.¹

Butyl rubber is a polymer known for its low water-vapor permeability. Its application as a water-vapor-barrier coating has been more attractive since the development and introduction of low-molecular-weight butyl rubber (butyl LM) with room-temperature curing. The DSC data show it to be thermally stable up to 200°C.

Because of the inherent oxidative aging stability, butyl LM coating formulations have been developed particularly for the protection of PU foam used as roof insulation.^{2,3} From the recommendation of the butyl producer, Exxon Chemicals, samples of butyl coating compounds PC8101/66 and Foamseal 57-80 were obtained. The compounds contain carbon or aluminum filler, which is not essential to our applications and could be removed if so desired. By the use of a brush-coating method, very satisfactory coatings were prepared on the foam specimens for the WVTR determination. The coating thickness was varied from 0.010 to 0.020 in. with multiple coats.

Polyvinylidene chloride (PVDC) also is noted for its very low vapor permeability. A PVDC latex, Daran 220 (made by W. R. Grace and Co.), and an experimental latex, XD-4653 (made by Dow Chemical Co.), were tried as coatings. They all formed poor coatings on the foam with

¹H. Yasuda and V. Stannet, *Encyclopedia of Polymer Science and Technology*, Vol. II, John Wiley & Sons, Inc., New York (1970), 317-327.

²H. H. Brillinger, *Am. Paint J.* (1970), 2-11.

³H. H. Brillinger, *Butyl Coatings for Protection of Spray Applied Polyurethane Foam*, *Proceedings of SPI 3rd International Cellular Plastics Conference*, 26-29 September 1972, Montreal, Quebec, III (1972).

bubbles and crazing. Similar problems were experienced with Saran F310 (Dow Chemical Co.), which was used in solution in different organic solvent systems. Apparently, the film formation was too rapid with solvent trapped, and the adhesion to PU foam was poor.

Epoxy is a popular coating material. Satisfactory coatings were prepared with Hysol PC-12-007, a good conformal coating compound. As shown later by the WVTR data, epoxy is a relatively poor vapor barrier for the foam in comparison to the butyl.

3.2 Water-Vapor Transmission

The WVTR's were measured at 70°C and 91-percent RH. Some early experiments were made at 51°C and 95-percent RH. The rough data obtained indicate that the rates at 51°C are only about 1/3 of those at 70°C. The 70°C temperature is the upper limit of military storage. We believe that measurements made at the extreme storage temperature should be more revealing with regard to the difference of the coating materials.

Tables II and III record all the WVTR data. Foams of 6- and 24-lb/ft³ densities are most frequently used in our potting applications. It has been our practice that 24-lb/ft³ foam is obtained by foaming 18-lb/ft³ material (Isofoam PE-18) in a closed fixture. The 1:4 ratio of the two foam densities is shown to have resulted in a 9:1 ratio of their WVTR's--a tremendous effect of foam density. The foam used in this work is a polyether type PU that has been shown to have good hydrolytic stability.⁴ Lee and Lion have defined the term "foam diffusivity" in comparison to the diffusion constant of the base polymer. They have shown that the foam diffusivity of a closed-cell foam is related to the gas diffusivity in the base polymer, the solubility coefficient of the diffusing gas in the base polymer, and a foam density dependent factor.^{5,6} Of course, the theoretical analysis

⁴A. B. Goldberg and P. F. Bruins, *The Effect of Hydrolytic Degradation on the Dielectric Properties of Polyurethane Foams*, SPE ANTEC, SPE Inc., 32nd Annual Tech Conference, Tech Papers, XX (May 1974), 298-300.

⁵W. M. Lee and D. W. Lion, *Mechanical Properties of Plastic Foams: A Model for the Effect of Aging*, Proceedings of the 1971 Kyoto International Conference on the Mechanical Behavior of Materials, III (1971).

⁶W. M. Lee, *J. Cell. Plast.*, 9, No. 3 (1973), 125.

TABLE II. WATER-VAPOR TRANSMISSION RATES OF 24-lb/ft³ POLYURETHANE FOAM* AT 70°C AND 91-PERCENT RELATIVE HUMIDITY

| Coating | Nominal thickness (in.) | Specimen No. | WVTR (g/m ² /24 hr) | Permeance (metric perms) | WVTR reduction (%) |
|---------------------------------|-------------------------|--------------|--------------------------------|--------------------------|--------------------|
| (Foam without coating) | | 1 | 30.0 | 0.14 | |
| | | 2 | 38.7 | 0.18 | |
| | | 3 | 46.1 | 0.22 | |
| | | Av | 38.3 ± 8.1 | 0.18 ± 0.04 | 0 |
| Butyl (C) PC8101/66 | 0.010 | 1 | 18.8 | 0.09 | |
| | 2 | 20.0 | 0.09 | | |
| | Av | 19.4 ± 0.8 | 0.09 ± 0 | 49 | |
| | 0.020 | 18.4 | 0.09 | | |
| Butyl (A1) Foamseal 57-80 | 0.010 | 2 | 22.3 | 0.10 | |
| | | 3 | 23.2 | 0.11 | |
| | | 4 | 15.1 | 0.07 | |
| | | Av | 19.8 ± 3.7 | 0.09 ± 0.02 | 48 |
| Epoxy Hysol PC-12-007 | 0.010 | 1 | 24.0 | 0.11 | |
| | 2 | 36.8 | 0.17 | | |
| | 3 | 31.4 | 0.15 | | |
| | Av | 30.7 ± 6.4 | 0.14 ± 0.03 | 20 | |
| | 0.020 | 1 | 18.6 | 0.09 | |
| | | 2 | 14.3 | 0.07 | |
| | | 3 | 12.8 | 0.06 | |
| | | 4 | 12.0 | 0.06 | |
| | | Av | 14.4 ± 2.9 | 0.07 ± 0.01 | 62 |
| | | 0.020 | 22.9 | 0.11 | |
| | | 2 | 22.3 | 0.10 | |
| | | 3 | 27.7 | 0.13 | |
| | | Av | 24.3 ± 3.0 | 0.11 ± 0.02 | 37 |

*By ASTM C355-64 desiccant method; nominal thickness of plain foam specimen, 0.810 in.

of a closed-cell system is much simplified. In the actual WVTR measurements, complications arise due to the microscopic cellular heterogeneity, the presence of open cells, and possible water condensation and entrapment inside the foam. All these would contribute to deviations in the experimental results. In addition, imperfection in sealing of the specimens could be another factor that caused some large deviations in the data shown.

Coating materials were tried such as low-molecular-weight butyl rubber, PVDC latices and solutions, epoxy, PU, and reclaimed rubber compound. Only the two rubber compounds, PC8101/66 and Foamseal 57-80, and one epoxy material, Hysol PC-12-007, were found to form good coatings on the PU foam. Consequently, the WVTR's were measured with

TABLE III. WATER-VAPOR TRANSMISSION RATES OF 6-lb/ft³ POLYURETHANE FOAM* AT 70°C AND 91-PERCENT RELATIVE HUMIDITY

| Coating | Nominal thickness (in.) | Specimen No. | WVTR (g/m ² /24 hr) | Permeance (metric perms) | WVTR reduction (%) |
|---------------------------------|-------------------------|--------------|--------------------------------|--------------------------|--------------------|
| (Foam without coating) | | 1 | 272 | 1.3 | |
| | | 2 | 365 | 1.7 | |
| | | 3 | 354 | 1.7 | |
| | | Av | 330 ± 51 | 1.6 ± 0.2 | 0 |
| Butyl (C) PC8101/66 | 0.020 | 1 | 24.1 | 0.11 | |
| | | 2 | 38.0 | 0.18 | |
| | | 3 | 43.5 | 0.20 | |
| | | Av | 35.2 ± 10 | 0.16 ± 0.05 | 89 |
| Butyl (Al) Foamseal 57-80 | 0.020 | 1 | 13.3 | 0.06 | |
| | | 2 | 21.6 | 0.10 | |
| | | 3 | 17.1 | 0.08 | |
| | | Av | 17.3 ± 4.2 | 0.08 ± 0.02 | 95 |
| Epoxy Hysol PC-12-007 | 0.020 | 1 | 90.1 | 0.42 | |
| | | 2 | 116.0 | 0.55 | |
| | | 3 | 63.8 | 0.30 | |
| | | Av | 90.0 ± 26 | 0.42 ± 0.13 | 73 |

*By ASTM C355-64 desiccant method; nominal thickness of plain foam specimen, 0.810 in.

these coatings applied to the foam. All the coatings made significant reductions of the WVTR of the foam. The reductions range from 37 to 95 percent, except in one test. The butyl-coating material suppliers recommend a coating thickness of 0.020 in. For comparison, the epoxy coating thickness was made the same. One half of this thickness appears to be definitely insufficient for the aluminum powder-filled butyl coating (Foamseal 57-80), whereas it makes no difference for the carbon-filled butyl (PC8101/66). Both butyl rubbers showed significantly higher effectiveness as vapor-barrier coatings than did the epoxy. Foamseal 57-80 appears to be somewhat better than PC8101/66 when the coating is thick enough. The aluminum filler in Foamseal 57-80 is known to have little effect on the electrical resistance of the resin system.⁷ For low density foam, the importance and necessity of a vapor-barrier coating are dramatically demonstrated by the magnitude of the rate reductions. Even an epoxy coating can make a 73-percent reduction of the WVTR of the 6-lb/ft³ foam.

⁷H. L. Lee and K. L. Neville, *Handbook of Epoxy Resins*, McGraw-Hill Book Co., New York (1967), 14-33.

4. CONCLUSIONS

The WVTR measurements have shown that polyurethane-foam encapsulant alone cannot give satisfactory protection from moisture penetration. A vapor-barrier coating is necessary and is even more important for the low-density foams. Two butyl-rubber coating materials, PC8101/66 and Foamseal 57-80, and one epoxy, Hysol PC-12-007, were found to form good coatings on PU foam and give significant reduction of WVTR.

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